SEED GERMINATION AND ESTABLISHMENT ECOLOGY OF BIG SAGEBRUSH AND RUBBER RABBITBRUSH AND ITS RELATIONSHIP TO ARTIFICIAL SEEDING SUCCESS

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Seed Germination and Establishment Ecology
of Big Sagebrush and Rubber Rabbitbrush
and Its Relationship to Artificial Seeding Success

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A three-year study carried out by:

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In cooperation with:

INT-87223-CA Pinson Mining Company (Pinson Mine, Golconda NV)
INT-87224-CA Western Energy Company (Rosebud Mine, Colstrip MT)
INT-87222-CA Peter Keewit Company (Black Butte Mine, Point of Rocks WY) ← Bought out
INT-87244-CA Coeur Thunder Mountain (Thunder Mountain Mine, Yellow Pine ID)
INT-87222-CA Rocky Mountain Energy Company (Prospect Point Mine, Point of Rocks WY)
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Progress Report for NV950-IA8-001

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INTRODUCTION

Reclamation of mine disturbances in the semiarid western United States has emphasized perennial grasses as the main component of seeding mixes for revegetation. There are several reasons for this. Perennial grass seed is readily available at reasonable cost from commercial seed dealers, and planting methods for successful establishment from seed are well understood. In many instances, however, establishment of perennial grass cover does not meet reclamation objectives, which often include the necessity for reestablishing woody species on sites previously occupied by shrubland or mixed shrub-grassland. Methods for successfully obtaining stands of native shrubs from seed are only partly understood. This is particularly true for small-seeded shrubs such as big sagebrush and rubber rabbitbrush. These must be surface-sown for successful establishment. Enhancing establishment probabilities for surface-sown seeds presents problems distinct from the problems associated with drilling perennial grasses.

Logistics

The problem of reestablishing sagebrush from seed is common to minesites over a wide range of habitat types, although the specific taxa involved may be different. In the present study, we worked on seven different minesites in four states. Funding responsibility for the project was shared among cooperators. While this limited the scope of our activity on any one minesite, it permitted us to undertake research at a scale that would have been difficult to fund without the help of multiple cooperators.

Objectives

The general objective of this project was "to develop basic knowledge of the germination and establishment ecology of big sagebrush and rubber rabbitbrush, in order to increase seeding success on disturbed lands, including minesites and depleted rangelands". The study had the following specific objectives:

1) Characterize germination and establishment patterns and their variation as a function of seed origin for each species.

2) Determine the role of seed origin in successful seedling establishment on a series of sites of contrasting climate and seedbed conditions.

3) Relate characteristics associated with seed origin to the potential for natural spread at each site.

4) Determine the effect of variation in planting technique and seed bed conditions on establishment at each site.

5) Make recommendations with regard to optimum planting techniques under various site conditions for each species.

6) Develop guidelines for matching seed of appropriate origin to specific site characteristics, in order to enhance seedling establishment and reduce seeding costs.

Methodology

The project as developed involved three main aspects. The first aspect included laboratory work on habitat-related variation in germination patterns. Much of the work on rubber rabbitbrush was in the write-up stage when this project began, but the big sagebrush work was funded largely under its aegis. This part of the project also included work on differences in emergence patterns in the greenhouse under various degrees of drought stress.

The second aspect of the project dealt with small plot studies under field conditions. The primary object of these studies was to find out whether habitat-correlated differences in germination pattern observed in the laboratory would result in differences in emergence and survival across a range of habitats in the field. We also looked at the effects of mulch, soil texture, and competition on emergence and survival. In autumn 1987, the first small plot study was set up at three contrasting sites near Ephraim, Utah. The second small plot study, which added the dimension of periodic seed retrieval to understand the fate of unemerged seeds, was initiated at Hobble Creek Canyon near Provo in autumn 1988.

The third aspect of the study involved onsite experiments to develop planting techniques for big sagebrush. The first study, evaluating the effects of various seeding techniques, was installed in autumn 1987 at five minesites (Pinson NV, Beacon Pit NV, Prospect Point WY, Thunder Mountain ID, Rosebud MT). The second study, which dealt with enhancement of sagebrush establishment through snow-harvesting techniques, was initiated in autumn 1988 at four minesites (Pinson NV, Black Butte WY, Rosebud MT, Stibnite ID).

RESULTS

Most of the information obtained during the course of this project has been prepared for publication and is in review or in press at the present time. Manuscripts containing detailed research results are included as an appendix to this report:

1) Meyer, S. E., S. B. Monsen, and E. D. McArthur. (In press) Germination response of Artemisia tridentata (Asteraceae) to light and chill: Patterns of between-population variation. Botanical Gazette, June 1990.

2) Meyer, S. E., and S. B. Monsen. (In press) Habitat-correlated variation in mountain big sagebrush (Artemisia tridentata ssp. vaseyana) seed germination patterns. Ecology.

3) Meyer, S. E., and S. B. Monsen. (In review) Big sagebrush germination patterns: Subspecies and population differences. J. Range Management.

4) Meyer, S. E., and S. B. Monsen. (In press) Seed source differences in initial establishment for big sagebrush (Artemisia tridentata) and rubber rabbitbrush (Chrysothamnus nauseosus). In: Proc. Symposium on Cheatgrss Invasion, Shrub Die-off, and Other Aspects of Shrub Biology and Management. USDA Forest Service Gen. Tech. Report INT-.

5) Meyer, S. E. (In press) Seed source differences in germination under snowpack in northern Utah. In: Proc. Billings 1990 Symposium on Planning, Rehabilitation, and Treatment of Disturbed Lands.

6) Monsen, S. B., and S. E. Meyer. (In press) Seeding equipment effects on establishment of big sagebrush on mine disturbances. In: Proc. Billings 1990 Symposium on Planning, Rehabilitation, and Treatment of Disturbed Lands.

We plan to prepare one additional publication from project research. The results of the snowharvesting experiment were presented in poster form at the 1990 meeting of the Society for Range Management in Reno NV:

Meyer, S. E., S. Carlson, and S. B. Monsen. Sagebrush establisment enhanced by snowfence. Abstract No. 26, 43rd Annual Meeting, Society for Range Management.

This data set will be prepared for submission to the Journal of Reclamation Research in the next few months.

In the account that follows, we will summarize results contained in the appended manuscripts as well as giving a more detailed account of additional research findings.

Laboratory/greenhouse studies

Laboratory germination studies

In our laboratory germination work with rubber rabbitbrush, we clearly demonstrated the existence of habitat-correlated variation in germination pattern (McArthur et al 1987; Meyer and McArthur 1987; Meyer et al 1989--see appendix for copies of these papers). Seed collections from sites with severe winters germinated much more slowly under conditions simulating winter snowpack than collections from sites with mild winters. Severe winter collections also had a tendency to be dormant under autumn temperature regimes, while mild winter collections were always nondormant under these regimes. These differences were not strongly correlated with the subspecific identity of the seed collection except for subspecies of narrow ecological amplitude. Widely distributed subspecies showed the full range of habitat-correlated variation in germination response.

Results of big sagebrush work in the laboratory were similar to rubber rabbitbrush results (Meyer et al, in press; Meyer and Monsen, in press, in review--see appendix for copies of manuscripts). This is not too surprising, since the two species have many other features in common. Both are shrubby small-seeded autumn-flowering members of the sunflower family, and both produce abundant but short-lived seeds. Both species are characterized by transient seedbanks, i.e., there is little or no carry-over of seed from year to year. Both are widely distributed in the western United States, and they occur over roughly the same spread of habitat types. The major difference between the two species from a synecological point of view is that rubber rabbitbrush tends to be a seral species that does not persist on sites that have fully recovered from disturbance, whereas big sagebrush is a climax dominant species.

Most of our big sagebrush germination work was carried out with 70 seed collections made in 1986--basin, mountain, and Wyoming big sagebrush subspecies were about equally represented. We also included a few collections of black sagebrush (Artemisia nova), low sagebrush (Artemisia arbuscula), and silver sagebrush (Artemisia cana), although these are not included in the appended manuscripts. In general, black and low sagebrush collections behaved like mountain big sagebrush collections from sites with similar climates, while

silver sagebrush collections behaved more like Wyoming big sagebrush collections. There were no differences between species per se.

Habitat-correlated differences in germination response were easily detected in all three common subspecies of big sagebrush. Collections from cold winter sites tended to have more conservative germination responses under autumn temperature regimes, i.e., dormancy, light requirement, and/or slow germination rate. These differences were most marked for mountain big sagebrush. Cold winter site collections of all three subspecies germinated much more slowly under conditions simulating winter snowpack than collections from mild winter sites. All collections completed germination rapidly under conditions simulating spring (at 15°C after prolonged chill).

Our studies on habitat-correlated differences in germination response for rubber rabbitbrush and big sagebrush suggest that germination ecotypes exist within each species. In order to be of real adaptive significance, these ecotypic differences would be expected to act to increase the probability of seedling survival by timing germination appropriately in a particular habitat type. If this is true, it follows that seedlots planted into a habitat different from the habitat for which they are adapted could misread environmental cues and germinate at an inappropriate time. This would tend to decrease the probability of seedling survival and therefore of successful stand establishment.

Greenhouse emergence trials

The objectives of the greenhouse emergence trials were twofold, to learn whether differences in laboratory germination response would affect emergence under controlled conditions in the greenhouse, and to examine interactions between seed source differences in response and seedbed variables such as planting position, soil texture, and watering regime. All experiments were carried out with three contrasting collections of mountain big sagebrush:

Utah Hill UT	mild winter site
Browse Offramp UT	intermediate winter site
Park City UT	severe winter site

In the first experiment, all seeds were sown at 2-3mm depth in a mix of sand:peatmoss of 9:1 by volume. Pots were saturated at the time of sowing and resaturated at 2-day, 4-day, or 6-day intervals. Differences in total emergence as percentage of sown seeds were evaluated after 30 days.

Table 1. Results of first greenhouse emergence experiment (% of seeds sown).

Seed source	Irrigation Regime			
	2-day	4-day	6-day	Mean
Utah Hill	95	98	94	96a
Browse Offramp	81	74	51	69b
Park City	38	40	26	35c
Mean	71a	71a	57b	

In this experiment, the mild winter Utah Hill collection was insensitive to irrigation treatment, emerging rapidly and completely in all three regimes. The severe winter Park City collection had lower emergence at all three regimes, while the intermediate Browse Offramp collection showed the biggest reduction at the driest regime.

In the second experiment, watering intervals of 3, 6, and 9 days were used. There were two seed placements, 2-3mm and surface sowing. After 46 days at the indicated watering regimes, pots were resaturated and watering intervals were changed from 3 to 2 days, from 6 to 4 days, and from 9 to 6 days for an additional 26 days.

Table 2. Results of second greenhouse emergence experiment (% of seed sown).

Seed Source	Irrigation Regime					
	Moist (3/2)		Intermediate (6/4)		Dry (9/6)	
	Surface	Covered	Surface	Covered	Surface	Covered
Dry First Part						
Utah Hill	3	42	0	66	0	0
Browse Offramp	1	45	6	27	0	1
Park City	1	5	2	4	0	0
Mean	2	31	3	32	0	0
Moist Second Part						
Utah Hill	61	58	68	72	22	42
Browse Offramp	71	59	71	61	12	37
Park City	53	13	34	7	1	9
Mean	61	43	58	47	12	29

Results of the second greenhouse emergence experiment showed that under dry surface conditions, seeds emerged more successfully from shallow burial than from the surface. The reverse was true when moisture became less limiting. Emergence from shallow burial was generally reduced for the Park City collection, which had a higher proportion of light-requiring seeds in laboratory tests. This collection also had a slower germination rate that resulted in generally lower emergence under conditions of wetting and drying.

In the third greenhouse emergence experiment, we examined the effects of variation in soil texture on emergence of the three seed collections in different watering regimes. The soil textures used were sand, 9:1 sand:peat by volume, and 3:1 sand:peat by volume. The watering regimes were low stress (4-day interval with saturation initially and at each watering), high stress (4-day interval with no initial saturation and reduced quantity at each watering) and high to low stress (regime 1 for 30 days followed by regime 2 for 30 days). All seeds were planted at 2-3mm depth.

Table 3. Results of third greenhouse emergence study (% of seed sown).

Seed Source	Soil Texture								
	Sand			9:1 sand:peat			3:1 sand:peat		
	Moisture Stress			Moisture Stress			Moisture Stress		
	Low	High	High/Low	Low	High	High/Low	Low	High	High/Low
Utah Hill	93	56	66	89	2	48	92	6	41
Browse Offramp	80	22	56	57	5	58	64	1	63
Park City	49	2	12	39	1	8	37	4	9
Mean	74	27	45	62	3	38	64	4	38

In this experiment sand consistently gave the highest emergence percentages. The reason for this is not known. We had expected that adding peat would increase soil hydraulic conductivity, thus keeping the surface more continuously moist and promoting germination. The difference among soil textures was most pronounced at high moisture stress. Emergence percentages for Utah Hill seed were not affected by texture as long as moisture was nonlimiting, but adding peat severely reduced emergence at high moisture stress. Park City seed emerged very poorly at high moisture stress regardless of soil texture and generally had the reduced emergence observed in previous tests. Emergence percentages failed to recover to levels comparable to low stress levels after removal from high to low stress moisture regimes. This suggested some preemergence mortality and prompted us to attempt an experiment that would permit physical recovery of unemerged seeds.

In the last greenhouse emergence experiment, we used fine sand as the potting medium and placed a nylon screen at a depth of 1 cm in each pot to permit retrieval of unemerged seeds at the end of the experiment. We used 2 planting depths, surface sowing and 2-3mm burial. Two watering regimes representing high and low stress were imposed. We counted emerged seedlings through 28 days, then removed remaining seeds to a 15°C growth chamber (12-hour photoperiod) for a 14-day incubation. Germinated seeds were removed every other day. At the end of the incubation period remaining seeds were subjected to tetrazolium staining to determine whether or not they were still viable. These data were used to calculate emergence percentage, seedbank percentage (buried viable seeds), and total viable seed percentage (sum of these two values) for each treatment.

In this experiment we were able to track the fate of seeds that did not produce emerged seedlings. We learned that, under the conditions of this experiment, many seeds either germinate but fail to emerge or die prior to germination. The Park City collection was able to conserve a higher proportion of ungerminated viable seeds in the high stress treatments than the other two seed collections. Its more conservative germination patterns would permit it to maintain a seed bank through autumn storm conditions simulated in these experiments. The Utah Hill seed collection, on the other hand, would tend to gamble its entire seed reserve under these conditions.

Table 4. Results of fourth greenhouse emergence experiment (% of seed sown).

Seed Source	Irrigation Treatment			
	Low Stress		High Stress	
	Surface	Covered	Surface	Covered
Emergence Percentage				
Utah Hill	63	87	0	50
Browse Offramp	52	68	0	35
Park City	5	25	0	0
Mean	40	60	0	28
Seedbank Percentage				
Utah Hill	0	0	27	2
Browse Offramp	3	12	33	11
Park City	39	37	55	70
Mean	14	16	38	28
Total Viable Seed Percentage				
Utah Hill	63	87	27	52
Browse Offramp	55	80	33	46
Park City	44	62	55	70
Mean	54	76	38	56

This series of experiments on greenhouse emergence raised more questions than it answered, and more work would be necessary before we could consider publishing them. All these experiments were carried out with unchilled seeds under autumn temperature regimes and do not tell us anything about the responses of chilled seeds in the spring, when most big sagebrush emergence actually takes place. They do show that a warm winter collection (Utah Hill) was more likely to germinate quickly and completely under conditions simulating autumn than a severe winter collection (Park City).

<u>Small plot emergence studies</u>

In the small plot emergence studies, we used seedlots that were collected from populations included in earlier germination work, so that we could predict their responses under field conditions in particular habitats. These newly collected seedlots were subjected to the same series of laboratory germination

trials as the original seedlots. Their behavior in these trials was always consistent with previously obtained results.

Ephraim field plot study

Results of this study, which was initiated in November 1987, are reported in Meyer and Monsen (in press, see appendix for copy of paper). We chose three field sites for this study, a Wyoming big sagebrush site, a pinyon-juniper site, and a mountain brush site. At each site we planted ten seed accessions, five of big sagebrush and five of rubber rabbitbrush. We then monitored seedling emergence and survival from the time of snowmelt the following spring through the course of the summer. We found that weather conditions at each field site had an overriding effect on the absolute number of seedlings to emerge and survive, but that collections of each species that did best at any one field site were those collected from sites with similar climates. These results confirmed the importance and relevance of the variations in germination pattern that we had measured in the laboratory, at least under the field conditions prevailing at the field plot sites during the year of the study. We also learned that we would have to improve replication in order to get clean differences between sources or treatments due to the increased heterogeneity that is an inevitable consequence of working under field conditions. It also became clear that a companion study involving retrieval of planted seeds at various points after sowing would yield valuable information on the fate of seeds that failed to produce emerged seedlings.

Hobble Creek retrieval/emergence plot study

In November 1988 we initiated another field plot study utilizing three collections each of big sagebrush and rubber rabbitbrush:

Rubber Rabbitbrush collections

Leeds UT (warm winter site)
Nephi Canyon UT (intermediate winter site)
Hailstone Jct. UT (cold winter site)

Big Sagebrush collections

Veyo Road UT (warm winter site)
Mayfield UT (intermediate winter site)
Prospect Point WY (cold winter site)

This study was conducted on Utah Division of Wildlife land in the mouth of Hobble Creek Canyon just east of Springville, Utah (see Meyer 1990 for details). The emergence plots were replicated ten times. Five plots of each accession were planted in a loamy soil area with very little gravel, while five were planted in a more gravelly area about 200 yards to the north.

In the area adjacent to the loamy soil plots, we placed mesh packets of seeds of each accession on the soil surface, sprinkled them with straw mulch, and covered them with hardware cloth cones to protect them from disturbance. Seeds of three accessions each of antelope bitterbrush, Palmer penstemon, and firecracker penstemon were included in addition to the big sagebrush and rubber rabbitbrush accessions listed above, a total of 15 packets under each cone.

Two series of 12 cones were laid out to permit retrieval of one cone from each series (i. e., two replications) at intervals through the winter and spring.

Results of the seed retrieval experiment are reported in Meyer (1990--see appendix for a copy of the paper). Seeds of the rubber rabbitbrush accessions germinated in the same order and at about the same rate under snowpack in the field as they did in the laboratory at a constant 1°C. The big sagebrush seeds germinated more slowly under snowpack than they did in laboratory chill, possibly because of a difference in light regime. The differences among accessions were not as pronounced in the field as in the laboratory, but the rank order of germination rate was the same.

The study site was continuously under snowpack from within 24 hours of sowing in late November until the first week of March, a fairly unusual circumstance for this kind of site, which usually bares off at least once during winter. After snowmelt, there were no severe frosts (lowest surface temperature -3°C). Yet the spring was cool and there was additional precipitation at regular intervals through June. In short it was an ideal situation for seedling establishment. The two sets of field plots were read at approximately weekly intervals from within a week after snowmelt through May, and again in late summer. Results are outlined in Table 5 below.

Table 5. Results of Hobble Creek emergence study. Emergence and absolute survival data are expressed in terms of percentage return on seeds sown. Relative survival is expressed as percentage of emerged seedlings surviving (i.e., final seedling number divided by maximum seedling number).

Seed Source	Loamy soil plots				Gravelly soil plots			
	% Init. Emerg.	% Max. Emerg.	Abs.% Surv.	Rel. % Surv.	% Init. Emerg.	% Max. Emerg.	Abs.% Surv.	Rel % Surv.
Rabbitbrush								
Leeds	34.1	34.1	13.9	40.8	36.4	36.5	0.8	1.6
Nephi Cyn.	35.5	35.5	21.2	59.7	42.1	62.9	4.7	7.5
Hailstone Jct.	26.7	26.7	16.7	62.5	19.0	48.7	1.6	4.4
Mean	32.1	32.1	17.3	54.3	32.5	49.4	2.4	1.2
Sagebrush								
Veyo Rd.	24.9	24.9	9.2	36.9	7.0	42.9	3.3	10.9
Mayfield	16.8	16.8	8.6	51.2	17.6	36.1	3.6	10.0
Prospect Point	9.3	16.9	12.2	36.9	30.1	30.4	3.3	12.1
Mean	17.0	19.5	10.0	41.7	18.2	36.5	4.0	11.0

The striking difference in results between the loamy soil plots and the gravelly soil plots overrides any source differences observed in this experiment. Maximum emergence in the gravelly plots was much greater for both species than maximum emergence in the loamy plots. The seedlings in the loamy plots emerged quickly, whereas those in the gravelly plots showed an emergence delay of over a week. But seedling mortality in July was four to five times greater in the gravelly plots than in the loamy plots. Another effect noticed but not quantified was a marked difference in seedling size and vigor between the two soil types. The loamy soil seedlings that survived achieved heights of 10 to 20 cm by the end of the summer, and some of them even flowered. The gravelly plot seedlings, in contrast, were 2 cm in height or less, and all were in a low vigor condition in September.

There are several possible explanations for this difference in response in the two soil types. The first is that the gravelly soil was excessively drained and dried out too quickly to permit adequate root growth. Another factor was the difference in weedy species composition on the two sets of plots. The loamy soil plots had mainly broadleaf forb weeds such as annual sunflower that were controlled easily by handweeding, whereas the gravelly plots were dominated by bulbous bluegrass. These plots could not be handweeded without uprooting the tiny shrub seedlings. We had not designed the study to quantify differences between the two plot areas--splitting the experiment into two areas was necessary in order to have the space to replicate. But as is often the case in science, this serendipatous result has given us some additional clues regarding factors that affect shrub seedling recruitment. Detailed studies to separate the effects of soil texture from those of competition are planned. The spectacularly different results obtained under essentially uniform weather conditions at two closely adjacent plot sites emphasizes the fact that weather is not the only overriding factor in the success or failure of shrub seedings.

The effects of seed accession on success or failure were not very marked in this study. All accessions did very well in the loamy soil plots, with seed returns from 9 to 12 % for sagebrush and from 14 to 21% for rabbitbrush. The lack of effect of seed accession was probably due to optimal weather for seedling establishment, i. e., no challenge from either midwinter or spring frost or from drought. This kind of result may explain how people get away with seeding nonadapted seed sources in certain years. It does not change the fact that the odds for successful stand establishment are improved by seeding an adapted seed source. We plan more emergence/retrieval studies to evaluate the importance of seed source in different kinds of weather years.

Onsite seeding studies

Seeding equipment effects

A study to evaluate the effect of various mechanical seeding techniques on sagebrush establishment was initiated in autumn 1987 at five mine sites. Locally collected seed was used at each site. Exceptionally dry winter conditions at Pinson Mine (near Winnemucca, Nevada), Prospect Point Mine (near Rock Springs, Wyoming), and Rosebud Mine (Colstrip, Montana) resulted in little or no emergence regardless of seeding treatment. Plots seeded at the Thunder Mountain Mine (near Yellow Pine, Idaho) were inadvertently destroyed by heavy equipment operators before evaluation could be carried out. Plots at the Beacon Pit Mine, an abandoned barite mine near Battle Mountain, Nevada, were had excellent emergence following meltoff of late winter snow in early March.

Results of the seeding equipment trials at the Beacon Pit Mine are reported in Monsen and Meyer (1990--see appendix for copy of paper). Seeding treatments that placed the seed into the surface of a firm seedbed (broadcast seeding, Oyer row seeder, Brillion cultipack seeder) resulted in the highest emergence percentages, while drill and broadcast/harrow treatments had reduced emergence. Survival of emerged seedlings was highest in treatments that scattered the seed (broadcast, broadcast and harrow), while treatments that placed the seed in rows (drill, Oyer row seeder) had reduced survival, presumably because of self-thinning. Jute mulch resulted in higher initial emergence but seedling densities in mulch and no mulch treatments a year after initial emergence were similar.

Results indicate that broadcast seeding is an adequate planting method for sagebrush as long as a firm (not compacted) seedbed is available. Sagebrush seed should not be drilled.

Snow harvesting

The failure of planting technique to overcome problems associated with inadequate winter moisture in the experiment described above prompted us to explore other ways of enhancing sagebrush emergence and survival in marginal moisture years. We installed an experiment designed to evaluate the effects of macrostructures (snowfence) and crimped straw mulch on snow accumulation and on subsequent emergence and survival of sagebrush seedlings. The following brief account of the results is taken from the text for the poster presented at the 1990 Society for Range Management meetings:

ABSTRACT

Small-seeded native shrub species such as sagebrush (Artemisia) have proven difficult to establish from seed on mine disturbances. Seeds must be placed near the surface, where rapid drying may prevent successful emergence. In this field experiment, snow harvesting using snow fence and straw mulch in factorial combination was used in an effort to enhance sagebrush establishment at four western minesites. At an eastern Montana mine, above-average winter moisture resulted in good stands regardless of treatment. In northern Nevada, an average moisture year produced a sixfold increase in establishment in snow fence plots. At high elevation mines in central Idaho and southwestern Wyoming, both snow fence and straw mulch resulted in enhanced emergence. Snow fence may be useful in establishing shrub patches which can serve as centers for natural recruitment into adjacent areas.

INTRODUCTION

Mine reclamation plans often call for reestablishment of native shrub species as well as perennial grasses and forbs. Many factors contribute to poor seeding success with shrubs, including incorrect planting methods, use of poorly adapted ecotypes, and failure to control competition from weeds and other seeded species.

One factor in seeding success commonly considered beyond control is the weather. Especially on semiarid sites, a dry

winter can result in failure of even the best-planned seeding. This problem is most acute for small-seeded surface-emerging species like sagebrush.

Natural recruitment in sagebrush stands often occurs even in marginal years. Our hypothesis was that adult plants act to ameliorate seedling microenvironment by trapping snow, thereby extending the period of favorable surface moisture later into the spring.

In this cooperative study with mines in four western states, we tested the hypothesis that snowharvesting would enhance sagebrush emergence and establishment, especially in marginal years.

OBJECTIVES

1) To test the effectiveness of snow harvesting in enhancing sagebrush seedling emergence and establishment at four contrasting western minesites.

2) To compare the effectiveness of snow fence and straw mulch, alone and in combination, as snow harvesting techniques.

3) To relate the effectiveness of snow harvesting treatments to weather conditions at each minesite.

METHODS

Experiments were established in autumn 1988, using similar plot layouts at all four sites. The sites were prepared by ripping, topsoiling, disking, and harrowing to provide a firm seedbed. Snowfence was then erected, and straw was crimped in for the mulch treatments. Plots were seeded by broadcasting with a hand-pulled fertilizer spreader. The seed was mixed with rice hulls to give a uniform seeding rate of approximately 50 seeds (P.L.S.)/square foot. The seed source for each site was a locally adapted species and ecotype.

Plot evaluation took place approximately two weeks after spring snow melt-off at each site, and again in mid to late summer. For each 10 X 10 foot plot, all sagebrush seedlings within three 10 X 1 foot strips (30% of total area) were enumerated using a one foot square sampling frame.

Results were analyzed for each site using appropriate analysis of variance techniques. The least significant difference test was used for means separation ($P<0.05$). Seedling counts were converted to a return-on-seed basis (seedlings/seeds sown) for graphic representation.

STUDY SITES

Mine	Elev.	Vegetation	Seeded Species
Rosebud	3175'	shortgrass prairie	Silver Sagebrush
Pinson	4895'	sagebrush steppe	Wyoming Big Sagebrush
Black Butte	6700'	sagebrush steppe	Wyoming Big Sagebrush
Stibnite	6400'	spruce-fir forest	Louis Sagewort

RESULTS

At the Rosebud Mine, above-average winter moisture resulted in excellent emergence and survival regardless of snow harvesting treatment (see Figure 1). In this kind of year, snow harvesting produces no net increase in recruitment.

At the Pinson Mine, an average moisture year provided enough winter snow cover in the snow fence treatment to produce six times as many established seedlings as the no snow fence treatment. Straw mulch had a negative effect. Even the control treatment gave adequate return on seed.

At the Black Butte Mine, a marginal moisture year gave lower return on seed than at Pinson or Colstrip, with no observed emergence in the control treatment. Both snow fence and straw mulch significantly improved establishment.

At the Stibnite Mine, observed emergence was minimal, possibly due to killing frosts after snowmelt. A combination of snow fence and straw mulch resulted in significantly higher emergence. No living seedlings were noted on the second sampling date.

CONCLUSION

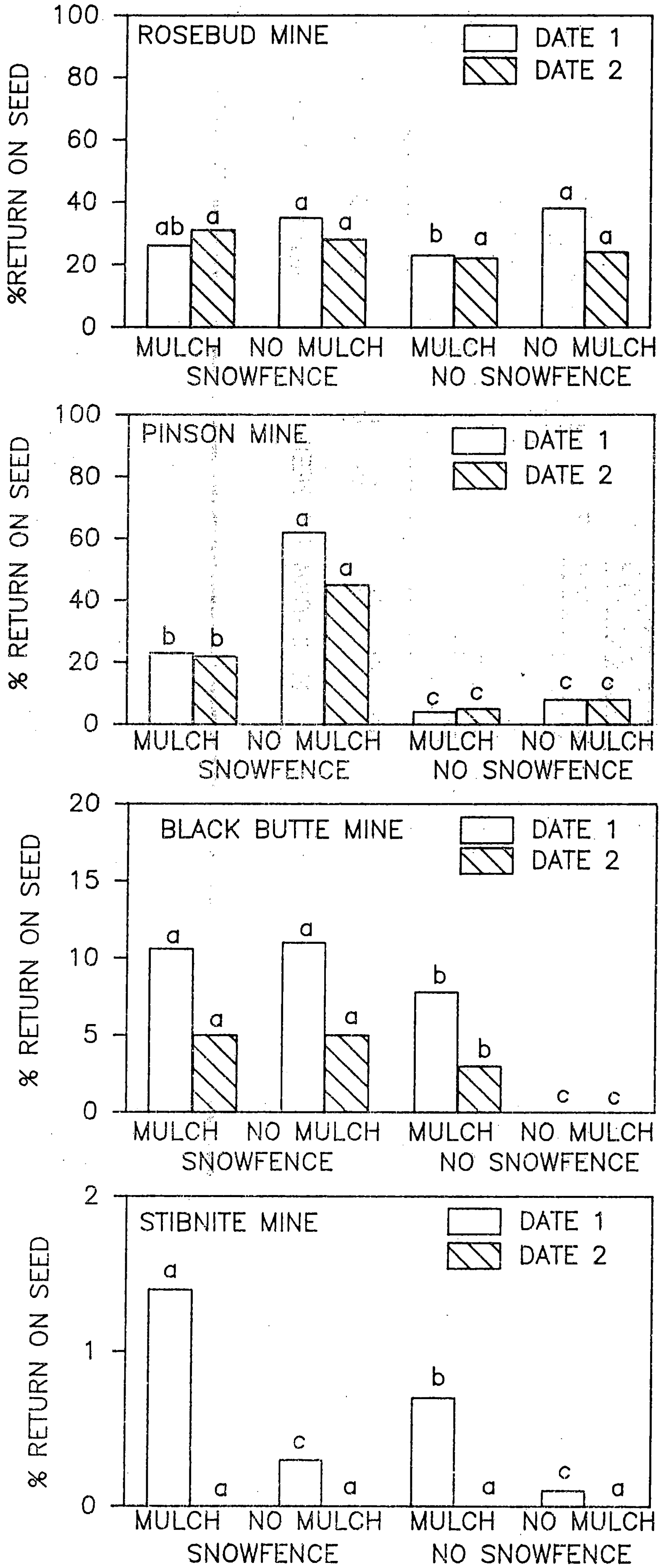
Results of this study indicate that snow harvesting techniques could be used effectively to enhance establishment of sagebrush species on mine disturbances in marginal moisture years. Small scale snow harvesting combined with intensive shrub seeding could be used to establish shrub patches that serve as centers for continued natural recruitment. These patches could be seeded without competition from aggressive perennial grasses.

Snow harvesting may also prove useful for increasing the effective chill period for shrub species with dormant seeds, such as bitterbrush, serviceberry, and wild rose. The establishment of shrubs in patches rather than interseeded rows creates a better prospect for long term persistence of all components of the seeded community.

Natural recruitment studies

Recruitment studies were not proposed as a formal part of the research to be included in this cooperative agreement, but we are including some preliminary results from ongoing studies at the Beacon Pit Mine. These studies are being funded on a yearly basis by the Battle Mountain, Nevada, BLM.

We followed rubber rabbitbrush recruitment on the plots sampled for the seeding equipment study described above and in Monsen and Meyer (1990). Rubber rabbitbrush is the principal native seral species at this site. In the following table we report the mean number of seedlings per square foot in each treatment on the mid-August 1988 sampling date. These seedlings emerged along with big sagebrush the previous March.



ROSEBUD MINE
DATE 1
DATE 2
%RETURN ON SEED
100
80
60
40
20
0
ab
a
a
a
b
a
a
a
MULCH
NO MULCH
MULCH
NO MULCH
SNOWFENCE
NO SNOWFENCE
PINSON MINE
DATE 1
DATE 2
% RETURN ON SEED
100
80
60
40
20
0
b
b
a
a
c
c
c
c
MULCH
NO MULCH
MULCH
NO MULCH
SNOWFENCE
NO SNOWFENCE
BLACK BUTTE MINE
DATE 1
DATE 2
% RETURN ON SEED
20
15
10
5
0
a
a
a
a
b
b
c
c
MULCH
NO MULCH
MULCH
NO MULCH
SNOWFENCE
NO SNOWFENCE
STIBNITE MINE
DATE 1
DATE 2
% RETURN ON SEED
2
1
0
a
a
c
a
b
a
c
a
MULCH
NO MULCH
MULCH
NO MULCH
SNOWFENCE
NO SNOWFENCE

FIGURE 1

Table 6. Rubber rabbitbrush seedling recruitment on Beacon Pit plots.

Seeding Treatment	Mean	Jute Mulch	No Mulch
Broadcast	2.18	3.32	1.04
Broadcast/Harrow	2.98	4.24	1.72
Brillion	2.14	3.29	0.99
Oyer	1.93	3.25	0.61
Flexplanter Drill	2.64	4.05	1.22
Mean	2.37	3.63	1.12

Three times more rabbitbrush seedlings became established under jute than became established in the no jute treatment. This is probably due to the increased effectiveness of jute in trapping windborne seeds. The seeding treatments that produced the most surface roughness (flexplanter, drill, broadcast and harrow) also tended to trap more rabbitbrush seeds and therefore yielded more established seedlings than smooth surface treatments (broadcast, Oyer, Brillion). The difference among seeding treatments was more marked in the no jute plots.

These results indicate that seedbed and moisture conditions suitable for big sagebrush establishment are also ideal for rubber rabbitbrush establishment. It could easily have been established trhough broadcast seeding had no local source of windborne seed been available. In this case the rubber rabbitbrush was dispersed effectively from nearby established populations (ca. 300 feet distant) and was able to take advantage of conditions provided by artificial seeding of big sagebrush. Whether or not this event was desirable is a matter of point of view. The presence of rubber rabbitbrush volunteers in the plots did not prevent the successful initial establishment of the seeded shrub species, big sagebrush. Just how the established seedlings will sort themselves out will be observed on future sampling dates. Another cohort of rabbitbrush seedlings became established in spring/summer 1989 (data not shown).

To give some perspective on the desirability of rubber rabbitbrush as a pioneer or early successional species on semiarid mine sites, we present some population data also obtained from the Beacon Pit Mine in 1989. The sampled area was coarse gravel waste that was seeded to a grass-shrub mixture that included big sagebrush in 1979. The original seeding resulted in sporadic stands, and at the time of the 1989 sampling the site was clearly dominated in terms of biomass by rubber rabbitbrush that had colonized the area on its own.

The focus of our sampling was on the relative numbers and size class distribution of rubber rabbitbrush and big sagebrush individuals in the area. We counted and measured all individuals of each species in 30 randomly selected 100 square meter plots. The two species were roughly equally represented in terms of numbers of individuals per square meter (1.80 for rubber rabbitbrush and 1.72 for big sagebrush). But the size class distributions were strongly contrasting. Information in the table below shows that most of the rubber

rabbitbrush individuals were in adult size classes, while a majority of the big sagebrush individuals were in juvenile and subadult size categories.

Table 7. Percentage of individuals of each species in each of 8 size classes.

Species	Size (height) class (cm)							
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	>70
Rubber Rabbitbrush	0.8	12.7	27.2	15.7	15.3	8.9	12.1	7.2
Big Sagebrush	7.3	35.6	27.3	14.2	8.3	4.0	3.1	0.2

These results strongly support the following scenario. Rubber rabbitbrush was able to colonize the site initially, in the years immediately following the artificial seeding attempt, whereas big sagebrush was not. The presence of rubber rabbitbrush exercised some ameliorating influence on seedbed conditions that permitted big sagebrush to begin to establish into rubber rabbitbrush stands. Once big sagebrush began to get a hold on the site, rubber rabbitbrush recruitment diminished. This is a classic scenario of the replacement of an early seral by a late seral species. This area was not topsoiled prior to artificial seeding in 1979, and the material was apparently too coarse and well drained to permit sagebrush establishment. The presence of rubber rabbitbrush has promoted the accumulation of fines in coppice mounds. This increase in soil fines, coupled with improved surface moisture conditions created by local snow accumulation and reduced insolation around the rabbitbrush plants, has permitted big sagebrush recruitment.

One approach to semiarid site shrub reclamation suggested by this scenario is to seed rubber rabbitbrush onto coarse-textured spoils, let the rabbitbrush act to accumulate soil fines and organic matter for a few years, then broadcast seed big sagebrush into the rabbitbrush stand.

RECOMMENDATIONS

Seed-related problems

Species/ecotype selection

From studies funded by this project we have determined that the germination attributes of sagebrush and rubber rabbitbrush are much more variable than earlier expected. Climatic conditions at the collection site strongly influence timing of seed germination of seeds produced at a particular location. The germination characteristics of a seedlot remain fixed, even if seeds are planted at a contrasting site. Seeds from warm locations that are conditioned to germinate quickly and early in the season are likely to succumb to frost if planted at a cold location. In contrast, seeds from cold climates that are conditioned to delay germination may germinate too late to survive rapid drying conditions when planted at warm locations. Seed zones have not been established to separate ecotypes with different germination features. Thus, seed buyers should purchase seed from locations similar to their planting

sites. This would insure the use of an adapted ecotype. Each seed source has a range of adaptation and if planted during years of favorable moisture and temperatures, will probably establish and survive at a number of different locations. However, most sagebrush communities are subjected to irregular climatic conditions, and planting success is quite erratic. Consequently, every attempt should be made to eliminate the risks involved in seeding, and planting marginally adapted ecotypes is not advised.

Individual mine companies should attempt to develop seed sources of adapted ecotypes, or identify and purchase seed sources that have proven adapted to their planting conditions. Either of these two practices is not too expensive or difficult to employ. Most mine sites include areas that support stands of native species. These areas may be small and obscure, but often respond well to protection from livestock grazing or other uses. The areas could become important seed production sites. Areas adjacent to mine locations can also be set aside as seed producing centers through cooperation with land management agencies. These sites can be managed to produce more consistent seed crops by irrigation, thinning, mowing, or protection from grazing. Most commerical seed collectors locate and collect seed from such isolated or protected areas. Sites that are intermixed within mine locations, conservation centers, parks, or roadways are the principal locations where most seeds are presently harvested. Mining companies can locate and manage these areas for contract harvesting.

If seeds are to be purchased from commercial vendors, mine companies should identify collection sites where seed is to be harvested. State seed certification agencies can be employed to monitor commercial harvesting and cleaning operations to assure the desired source is provided. Mine revegetation plans are normally developed far enough in advance to allow the purchase of appropriate ecotypes. Seed can be purchased or harvested during years of high production and stored for future planting.

Seed quality/storage

Seed quality is an important issue with sagebrush. Seeds normally ripen in the fall, and it is difficult to harvest, process, and plant the seed in the same season. Since fall seedings are usually more successful than spring plantings, fall-harvested seed is often collected and "stored-over" until the following year for planting. Seeds should be kept in a dry cool environment. If possible, seeds should be stored under refrigeration, but this is not necessary as long as seeds are not subjected to excessive hot or cold temperatures. Before planting, seed germination tests should be conducted, and seeding rates should be based upon current germination percentages. Germination tests can be completed within a few days or weeks by most seed laboratories.

Before cleaning the purity of most seedlots is usually quite low. Purity ranges from 10 to 15 percent for most uncleaned seedlots. Seeds are normally cleaned with a fanning-mill to remove large sticks and debris. Most seed is sold on a PLS (pure live seed) basis. Vendors normally process or clean seed to purity levels of 15-40 percent. Seeds are small and can be easily damaged by rough handling or improper cleaning. If the large debris is removed during cleaning, the seed can usually be seeded alone or with seeds of most other species using conventional seeders. Trashy seedlots can cause bridging and clogging problems in most seeders. Buyers should specify the purity and condition of the seed to be purchased.

Planting-related problems

Seedbed preparation

Seedbed requirements for seeding sagebrush are quite similar to those for many other species. A firm surface is required for best success. Soils should not be compacted or subjected to crusting or rapid drying. In addition, soils that contain a high percentage of rock in the surface are not conducive to sagebrush establishment. Undisturbed soils that contain considerable rock, but are relatively stable with some litter and organic matter provide suitable planting sites. However, mine wastes and substrata that resemble crushed gravel or cobble size rock are not suitable sites for sagebrush.

Sagebrush seeds establish best from surface or very shallow planting (0-1/4 inch depth). To be successful, the surface must remain moist during the period of germination and seedling establishment. Soil surfaces that drain rapidly, crust upon drying or remain hard are not conducive to seedling survival. Any site preparation practice that creates compact or crusting surfaces will interfere with planting success. If possible, mine wastes should be topsoiled to enhance sagebrush establishment. Planting on loose unsettled surfaces is not advised. Unsettled soils tend to settle and seeds are buried too deeply. Seeding on a rough surface is a successful means of planting, but attempting to seed on soils that are very loose and unsettled is to be avoided.

Seeding techniques

Planting dates--Seeding in late fall or early winter is advised. Planting should be completed late enough in the fall to prevent fall germination. Spring seedings have been successful, but must be conducted early enough to allow seeds to emerge before soils have dried. Sagebrush seeds benefit from the protective influence of a snow cover. Seed germination and seedling establishment are significantly enhanced by the favorable soil moisture and temperatures that exist under a melting snow blanket. To take advantage of the snow-covered seedbed, sites must be fall or winter seeded. Spring plantings can be enhanced by supplemental irrigation if available, but it is difficult to maintain a moist soil surface long enough to assure seedling emergence.

Seed placement/seeding equipment--Seeders that position the seed on or near the soil surface should be used. Most drill seeders plant too deeply. Although they can often be adjusted to plant shallowly, it is difficult to maintain seed placement within 1/4 inch of the surface. Surface seeders including the brillion seeder are available and suitable for most plantings. Broadcast seeding is appropriate and a satisfactory technique to be used. Broadcasting on a friable surface does not require follow-up covering. If surfaces are hard, harrowing before planting is necessary. Extensive harrowing after seeding should be avoided. Broadcast seeding on a snow cover has been quite successful, and is a common practice in many wildlife habitat improvement projects. It could be used to seed large mine disturbances.

Seeding rates--Seeding at a rate of 0.10-0.50 pounds of pure live seed per acre is sufficient for development of a satisfactory stand. Over-seeding (planting heavy amounts) to compensate for poor seedbed conditions is not advised. Sagebrush seeds are small (approximately 2 million seeds per pound); consequently it is difficult to regulate and uniformly distribute seeds on irregular terrain and planting surfaces. Seed is often mixed with a carrier to

provide enough bulk to more easily distribute the seed. Various studies have reported less than 0.01 percent return on planted seeds. In our studies returns of over 15 to 60 percent have been achieved. Assuming a return of 1.0 percent and a seeding rate of 0.15 PLS per acre, the number of plants to establish would be approximately 3,000 shrubs per acre, a satisfactory number.

In many situations sagebrush and other shrub seeds are planted in strips, rows or selected spots. Seeding rates should be based upon the actual area sown. If seedings are to be concentrated in rows it is not necessary to seed heavily as competition among seedlings will occur. Seeds should be uniformly distributed to avoid unnecessary competition.

Interspecific competition/control

Competition from weeds--Sagebrush seedlings develop rapidly but are not able to compete with weeds such as cheatgrass, annual kochia, mustards, etc. Prior to seeding, sites must be cleared of weeds. Although sagebrush seedlings do survive some competition, it is not advisable to plant areas with potential weed problems.

Interseeding into furrows or cleared strips is a means of seeding weed infested sites. Other techniques are available to avoid weed problems. Broadcast seedings on weedy sites are often done using sagebrush and rabbitbrush, but planting success is dependent upon the number of "safe sites" where seeds are deposited.

Once established, sagebrush seedlings compete well and survive adverse climatic conditions; consequently sagebrush stands often arise amid developing weedy fields. However, seedings should not be conducted in areas with extensive annual competition.

Competition from other seeded species--In most situations sagebrush should not be seeded directly with perennial grasses. If possible, shrub seedings should be separated from herbaceous species. Shrub seedlings including sagebrush are often better adapted to harsh mine sites than perennial grasses, and may establish much better than the herbs. But it is still advisable to reduce the chance of competition. Reducing the amount of grass seed sown can benefit shrub seedling survival. Although shrubs can be seeded directly with herbs in some areas, the decision to plant mixed seedings should be made on a site by site basis. Sagebrush seedlings are much more compatible with certain native species than they are with most introduced grasses. Consequently, sagebrush can be seeded in mixtures as long as compatible species are used. This practice should be promoted in mineland restoration.

Coping with year-to-year weather variation

Repeated seedings

Sites that receive less than 12 inches of annual precipitation are difficult areas to successfully seed. These locations often receive insufficient moisture to support emerging seedlings. Certain moisture conservation practices can be used to entrap and store water to aid in plant establishment, but these procedures are not always practical. It may be more economical in the long run simply to seed repeatedly using an inexpensive method such as broadcasting with conservative seeding rates until a year with adequate moisture for establishment is encountered.

Snow harvesting

Mulch/standing litter--Various types of mulch or litter are frequently used to conserve soil moisture, improve infiltration, and reduce high surface soil temperatures. These measures may also be effective in trapping snow and reducing losses due to evaporation. These procedures are particularly useful in improving seed germination and initial establishment. In our studies we used jute-netting as a mulch to improve seedbed conditions. Our results were somewhat different than expected. The use of the netting resulted in an increase in the number of seedlings to emerge, but fewer seedlings survived at the end of the first summer. We are unable to explain the decrease in seedling survival. However, planting an annual species to provide a stubble cover or adding long-fiber mulch such as straw to the soil surface are methods that can be used to collect moisture and decrease rapid drying.

Summer-fallowing of mine sites can be used to collect and conserve soil moisture prior to planting. This procedure requires preparation of the planting surface a year ahead of seeding. The site must be kept free of weeds, and tilled to promote infiltration of moisture. Considerable moisture can be stored in soils that have good soil texture and structure. Although moisture stored in the soil profile will help plant growth, it is not as beneficial to seed germination and growth of small seedlings. Surface moisture is most important to new or small seedlings. Soils may contain adequate soil moisture to germinate seeds, but the sites may dry rapidly preventing establishment. If germination can be completed beneath a melting snowpack, the seedbed remains moist and somewhat protected from rapid desiccation. This condition is important to seedling establishment, and procedures that can be used to trap snow and delay rapid and early melting should be considered, particularly in semiarid sites.

Macrostructures--The construction of snow fences or similar protective barriers are useful in trapping snow and increasing seedling establishment. The use of snow fences at the Pinson mine resulted in a six fold increase in sagebrush seedling establishment. In some situations complete seeding failures may result without snow entrapment. Large open areas that are subjected to wind and rapid drying are difficult sites to seed. Unless some means are provided to reduce rapid drying, these sites may not be successfully seeded except in years of high moisture. Other procedures including deep-furrowing may be used to modify the site and trap snow.

Standing shrub cover--Seedbeds may also be improved by the establishment of a shrub nurse-crop. Natural recruitment of sagebrush seedlings occurs quite regularly throughout native stands of mature plants. The overstory shrubs apparently provide protection to the soil surface. Snow or moisture is accumulated and rapid drying is prevented by the shrub cover. Transplanting shrubs in groups or clusters can be used to protect and modify the seedbed of the planted site and adjacent areas, provide a seed source, and allow natural spread of the sage. This practice is a viable method of planting mine sites. Another method is to seed a shrub that establishes more easily on open sites and allow it to ameliorate the site prior to seeding sagebrush. Use of rubber rabbitbrush in this context was described earlier.

Predicting success probabilities

Longterm weather patterns--The longterm weather patterns define areas that can be successfully seeded with reasonable regularity. Climatic conditions also define areas where difficulties may occur. Although climatic conditions can not be changed without extensive treatments, such as irrigation, an understanding of climatic influence upon planting success aids in developing seeding practices. It is important that sites are properly prepared and seeded at the appropriate date. Every effort should be given to assure success even though climatic conditions are unpredictable.

Midwinter seedings--Seedings can be delayed until midwinter to determine if sufficient moisture is available to assure success. Since sagebrush can be broadcast seeded on snow or the soil surface, it is practical to seed in late winter. Plantings can be completed in a short time by broadcast seeding. Consequently, it is possible to seed after or shortly before storm events. This practice could prevent seeding failures during years of low moisture.

GENERAL CONCLUSIONS/RECOMMENDATIONS

In this study we determined that germination and establishment patterns for big sagebrush and rubber rabbitbrush vary as a function of seed origin. These differences among seedlots can be critical to the success or failure of a seeding, particularly in marginal years. We strongly recommend that locally adapted seed sources be used whenever possible.

Use of correct seedbed preparation and seeding techniques can increase return on seed for big sagebrush in years when winter moisture is sufficient to permit emergence and establishment. Surface-planting on a firm seedbed using broadcast seeding or a seeder such as a Brillion cultipacker should produce adequate stands even with moderate seeding rates. Increasing seeding rates to compensate for poor planting techniques or lack of winter moisture is not effective. Efforts to minimize competition, both from weeds and from other seeded species (especially introduced perennial grasses) should be made.

Big sagebrush seeds germinate under snow or at the edge of melting snowpack. Late winter moisture is the best guarantee of successful emergence. Because these conditions are often not met in an average year on big sagebrush sites, techniques for redistributing snow are effective in increasing establishment success. This redistribution may take place naturally in existing shrub stands, but on open, windswept mine disturbances, it may be necessary to create wind barriers and plant shrub seeds in patches in resulting snow accumulation zones.

APPENDICES

The following manuscripts are included as appendices to this report:

Rubber rabbitbrush germination biology

McArthur, E. D., S. E. Meyer, and D. L. Weber. 1987. Germination rate at low temperature: Rubber rabbitbrush population differences. J. Range Manage. 40:530-533.

Meyer, S. E., and E. D. McArthur. 1987. Studies on the seed germination biology of rubber rabbitbrush. p.19-25. In: Johnson, K. L. (ed.). Proceedings of the fourth Utah Shrub Ecology Workshop. Utah State Univ., Logan.

Meyer, S. E., E. D.McArthur, and G. L. Jorgensen. 1989. Variation in germination response to temperature in rubber rabbitbrush (*Chrysothamnus nauseosus*: Asteraceae) and its ecological implications. Am. J. Bot. 76:981-991.

Big sagebrush germination biology

Meyer, S. E., S. B. Monsen, and E. D. McArthur. (In press) Germination response of *Artemisia tridentata* (Asteraceae) to light and chill: Patterns of between-population variation. Botanical Gazette, June 1990.

Meyer, S. E., and S. B. Monsen. (In press) Habitat-correlated variation in mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*) seed germination patterns. Ecology.

Meyer, S. E., and S. B. Monsen. (In review) Big sagebrush germination patterns: Subspecies and population differences. J. Range Management.

Small plot retrieval and establishment studies

Meyer, S. E., and S. B. Monsen. (In press) Seed source differences in initial establishment for big sagebrush (*Artemisia tridentata*) and rubber rabbitbrush (*Chrysothamnus nauseosus*). In: Proc. Symposium on Cheatgrss Invasion, Shrub Die-off, and Other Aspects of Shrub Biology and Management. USDA Forest Service Gen. Tech. Report INT-.

Meyer, S. E. (In press) Seed source differences in germination under snowpack in northern Utah. In: Proc. Billings 1990 Symposium on Planning, Rehabilitation, and Treatment of Disturbed Lands.

Onsite seeding studies

Monsen, S. B., and S. E. Meyer. (In press) Seeding equipment effects on establishment of big sagebrush on mine disturbances. In: Proc. Billings 1990 Symposium on Planning, Rehabilitation, and Treatment of Disturbed Lands.